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**AN ECONOMIC STUDY OF AN ADVANCED TECHNOLOGY  
SUPERSONIC CRUISE VEHICLE**

**Cynthia L. Smith and Louis J. Williams**

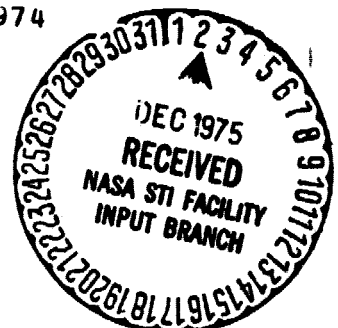
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16. Abstract  <p>This report presents a description of the methods used and the results of an economic study of an advanced technology supersonic cruise vehicle. This vehicle was designed for a maximum range of 4000 n.mi. at a cruise speed of Mach 2.7 and carrying 292 passengers.</p> <p>The economic study in this report includes the estimation of aircraft unit cost, operating cost, and idealized cash flow and discounted cash flow return on investment. In addition, it includes a sensitivity study on the effects of unit cost, manufacturing cost, production quantity, average trip length, fuel cost, load factor, and fare on the aircraft's economic feasibility.</p>			
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AN ECONOMIC STUDY OF AN ADVANCED TECHNOLOGY  
SUPERSONIC CRUISE VEHICLE

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SUMMARY

An advanced technology supersonic cruise vehicle concept study was recently completed for the Supersonic Cruise Aircraft Research (SCAR) Office at NASA's Langley Research Center. Since the study did not include an economic analysis, the former Systems Studies Division\* at NASA's Ames Research Center was asked to investigate the economic feasibility of the vehicle which evolved from the study.

The vehicle chosen as a nominal for the economic study was the aircraft designed for a range of 4000 n. mi. Its economic performance was analyzed with regard to sensitivity to aircraft cost, production quantity, range, fuel cost, load factor, and fare level. The economic performance was found to be most sensitive to the last four variables.

INTRODUCTION

The Hampton Technical Center of the LTV Aerospace Corporation recently completed a study of an advanced technology supersonic cruise vehicle (ATSCV) concept. Since this study did not include economic data, a supplementary effort was undertaken by the Systems Studies Division at Ames Research Center to investigate the economic characteristics of the vehicle defined in the LTV study.

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\*Since this paper was written, the Systems Studies Division has been dissolved and the Branch of the SSD responsible for this work has been renamed the Aeronautical Systems Office.

The nominal or baseline vehicle chosen for the cost study is the aircraft designed for a range of 4000 n. mi. The characteristics of this vehicle are shown in table 1; included in this table are the vehicle technical parameters as well as the cost assumptions.

The economic study involved calculating the nominal aircraft unit cost, operating cost, and idealized return on investment. After these quantities were determined, a sensitivity study was performed to analyze the effect of production quantity, unit cost, range, fuel cost, load factor, and fare on the various productivity indicators for the vehicle. This report gives a description of the methods used for the economic study and presents the results of that study. A complete report on the technical characteristics of the vehicles may be found in reference 1.

## METHOD OF ANALYSIS

The SSD has developed a computer program for the calculation of aircraft costs. This program is a combination of sets of individual programs which were developed to calculate specific areas of aircraft cost (e.g., unit cost, RDT&E, operating cost). Figure 1 illustrates the schematic flow of ACCOST.

The main program directs the flow into an input program where data to be used by the various subroutines is gathered. The flow then moves into a module which computes the research, development, test and evaluation (RDT&D) costs and the manufacturing costs. The RDT&E is then amortized over the production aircraft and used in generating the aircraft unit cost.

Next the operating cost subroutines estimate the direct and indirect operating costs and the idealized cash flow return on investment. The last set of subroutines encountered in the program uses discounting methods to produce an output of yearly cash flows over the aircraft lifetime and a final idealized discounted cash flow return on investment (ROI) for the aircraft.

ACCOST has been evolved over a long time period and reflects the experience gained through the costing of various types of aircraft programs.

#### AIRCRAFT PRICE

The aircraft price is calculated in ACCOST. Cost estimating relationships (CER) have been developed from the historical data, and these relationships are used to estimate the costs for RDT&E and for manufacturing. The RDT&E costs are amortized over the total production quantity.

The CER's are functions of the aircraft physical characteristics such as takeoff weight and speed, component weights, engine thrust, etc. The effects of learning, aircraft production rate, profit and other factors are included in the manufacturing costs.

#### OPERATING COST

Aircraft operating costs are comprised of direct and indirect operating costs. Direct operating costs (DOC) include flying operations and maintenance and depreciation of flight equipment. Flying operations

include flight crew, fuel and oil, and hull insurance cost. Maintenance of the flight equipment is broken into five categories: airplane labor, airplane materials, engine labor, engine materials, and maintenance burden. Since the 1967 ATA equations (ref. 2) have been used in this study, it is most convenient to consider the DOC's as falling into one of the following categories: flight crew; fuel and oil; direct maintenance; insurance; depreciation. The indirect operating costs (IOC) are composed of the following ten categories from the Boeing/Lockheed 1964 proposed IOC methodology (ref. 3):

1. Direct Maintenance (ground property and equipment) - System  
Depreciation (ground property and equipment) - System  
Maintenance Burden (ground property and equipment) - System
2. Direct Maintenance (ground property and equipment) - Local  
Depreciation (ground property and equipment) - Local  
Maintenance Burden (ground property and equipment) - Local  
Aircraft Servicing (except aircraft control)  
Servicing Administration (allocation to aircraft servicing  
except aircraft control and landing fees)
3. Aircraft Servicing (aircraft control)  
Servicing Administration (allocation to aircraft control)
4. Passenger Service (cabin crew salary and related expense)
5. Passenger Service (food and beverage)
6. Traffic Servicing (passenger handling)

- Servicing Administration (allocation to passenger handling)
- Reservations and Sales (except commissions)
- 7. Traffic Servicing (baggage and cargo handling)
  - Servicing Administration (allocation to baggage and cargo handling)
- 8. Passenger Service (except crew, food, beverages)
  - Reservations and Sales (passenger commissions)
  - Advertising and Publicity (allocation to passenger transportation)
- 9. Reservations and Sales (freight commissions)
  - Advertising and Publicity (allocation to freight transportation)
- 10. General and Administrative

Inflation factors were applied to bring the maintenance labor rates to 1974 dollars. Fuel cost in the nominal case was chosen at \$.0335/lb or \$.218/gal (ref. 5). Flight and cabin crew costs were escalated to reflect 1974 wage scales. The other cost assumptions--load factor (55%), utilization (3647 hrs/yr), and depreciation period (15 yr)--reflect the current operating environment.

Figure 2 illustrates the relative costs of each of the five DOC components for the nominal vehicle; at 41% of the total, fuel costs represent the major contribution to the DOC. For the IOC, 70% is included in categories 6, 8, and 10. Categories 6 and 8 account for passenger related expenses and category 10 is a function of the sum of the five DOC components and the first nine IOC components.



## RETURN ON INVESTMENT

While the operating cost is an important indicator of aircraft economic efficiency, the rate of ROI to the operator of the aircraft is the most desirable design criterion or figure of merit. However, computation of an accurate ROI involves life cycle costing and requires detailed information regarding route structures, production rates, program lifetime and other factors. Since such a computation is beyond the scope of the present study, a simplified idealized ROI was used. This idealized ROI is based on a single aircraft flying a year on routes at a given range. Although the absolute value of this idealized ROI has little meaning, it is felt to be accurate for comparison of options on a relative basis. The study computed two measures of idealized ROI; the first is cash flow ROI (CFROI) and the second is discounted cash flow ROI (DCFROI).

### Cash Flow ROI

CFROI is calculated as the ratio of the annual cash flow generated by the aircraft to the initial investment. The annual cash flow is the sum of the net profit and depreciation. It is computed as the after tax difference of annual revenue and operating costs, where operating costs are defined to include depreciation. Taxes are computed at the rate of 48% of net profits. The annual revenue is estimated by multiplying the passenger miles flown per year by the average revenue yield. The average revenue per seat was estimated with a fare structure of \$12 per boarding and \$0.0658 per mile; the configuration is all coach class. A 10% fare dilution was assumed to account for the effect of family plans, excursion rates, and other promotional fares. The investment is the ini-

tial value of the aircraft plus an additional 10% of the airframe cost for airframe spares and 40% of the engine cost for engine spares.

The CFROI is then a "snapshot" of the ROI in each year assuming that the value of money does not change as a function of time. Thus, the CFROI would be calculated by the following equation:

$$\text{CFROI} = \frac{\text{AR} - \text{TOC} + \text{DEP}}{\text{INV}}$$

where

AR - annual revenue = fare + annual passengers

TOC - total operating cost = IOC + DOC

DEP - depreciation

INV - investment (defined above)

### Discounted Cash Flow ROI

The DCFROI uses a discounting factor which accounts for money received in the distant future having less value than money received in the near future. By setting the present value of the future cash flows equal to zero, the computed return will be the project's internal rate of return, interest rate of return, profitability index, or DCF rate of return (DCFROI). This DCFROI is examined relative to the risks associated with the project and the investment decision made accordingly. For example, if a company's cost of capital is 8%, typical profitability objectives would be 12% for a very low risk venture, 16% for below average risk, 20% for average risk, 30% for above average risk, and 50% for a high risk venture (ref 6). The calculation of DCFROI incorporates the methods of compound interest computations where:

$$P = S \left[ \frac{1}{(1+i)^n} \right] \quad (1)$$

P - Present sum of money

S - Sum of money at the end of n periods from the present date  
date that is equivalent to P with interest

n - Number of interest periods

This formula is used in calculating the DCFROI in the following manner. First, a net cash flow (NCF) is computed for each year from the annual revenue minus the investment, operating cost, interest and income tax. Next the following substitutions are made in (1):

$NCF_K$  = Net cash flow for year K

$P = NCF_1$

$$S \left[ \frac{1}{(1+i)^n} \right] = \sum_{K=2}^n NCF_K \left[ \frac{1}{(1+i)^K} \right]$$

An iteration is performed on i until the two sides of the equation are equal; the resulting value of i is the DCFROI.

As the figures in the Results Section of this paper demonstrate, DCFROI is a much more sensitive indicator than CFROI. The most acceptable measure of economic potential is the DCFROI for consideration of future projects (ref. 7); however, this study also includes CFROI since this indicator is more familiar from many engineering studies.

Figure 3 is a graphical representation of both NCF and discounted

cash flow. Initially, revenues quickly offset the investments of 40% of the total purchase price for one aircraft (including 10% of the airframe cost and 40% of the engine cost for spares), but the effect of discounting is quite dramatic from the second year on through the life of the project. The cash flows shown are those of the nominal vehicle. The upturn in NCF in the last year reflects the positive cash flow for the residual value of the aircraft received from the sale of the vehicle at the end of the last year. The discounted cash flow barely shows this rise in income since the event occurs 15 years from the beginning of the discounting period.

The change in slope (particularly notable in the NCF) which occurs between the seventh and eighth years is caused by the change from a double-declining depreciation method (used in the first seven years) to a straight-line depreciation method.

## RESULTS

There are several factors that determine the unit cost of an aircraft. Although the detailed unit cost estimate is developed as a combination of the estimates on individual components based on different cost estimating relationships, it is primarily a function of aircraft empty weight, manufacturing cost as related to technology level, and production quantity.

### Effect of Empty Weight on Unit Cost

For a fixed production quantity and manufacturing cost level, the effect of aircraft empty weight on unit cost is shown in figure 4. Past

studies have indicated that the slope shown in figure 4 is generally true in predicting aircraft cost as a function of aircraft empty weight (ref. 9). If the SSD program had been used to calculate the Concorde cost at the same stage as the ATSCV program is now, the cost would have been estimated at \$29 million. However, this cost is for a production run of 400 aircraft and is an estimated cost, not price. The price charged for an aircraft is often dependent on many factors other than cost. The December 1974 price of the Concorde of \$47 million has been indicated on figure 4 for comparative purposes.

#### Effect of Manufacturing Cost on Unit Cost

The nominal aircraft unit cost calculations were based on the estimated manufacturing cost for titanium construction. Figure 5 shows the effect of this airframe manufacturing cost increase relative to conventional aluminum manufacturing cost experience. If the manufacturing cost of the airframe was reduced to that for aluminum construction, the aircraft unit cost would be reduced from \$58.6 million to \$52.4 million.

#### Effect of Production Quantity on Unit Cost

Figure 6 illustrates the effect of production quantity on aircraft unit cost. Increasing the number of vehicles from 200 to 400 reduces the unit cost from \$82 million to \$58 million--a decrease of 29%; however, increasing the number of vehicles from 400 to 800 only reduces the unit cost an additional 22%.

#### Effect of Unit Cost on DOC and ROI

Whether the change in unit cost comes about because of changes

in empty weight, manufacturing cost, or production quantity, the resulting effect on DOC and ROI is the same.

The effect of unit cost on DOC is shown in figure 7. The DOC is actually rather stable even though unit cost is increased. For example, a 20% increase in unit cost over the predicted cost of the nominal vehicle raises the DOC from 1.73 to 1.83¢/seat n. mi., an increase of only 5.8%. This relatively small increase should have little impact on the economic attractiveness of the vehicle.

Figure 8 illustrates the rate of change in the ROI as unit cost increases. An increase of 20% above the cost estimated for the nominal vehicle would cause a 15% decrease in CFRROI and a 36% decrease in DCFROI. The decrease in ROI as unit cost increases is the result of the decrease in the net cash flow; the annual revenue remains unchanged while increases are occurring in investment, operating cost, and interest.

If the change in unit cost were only due to changes in production quantity, this effect is shown directly in figure 9. CFRROI shows very little effect when the size of the production run is varied. The value of CFRROI increases only 13% when the production quantity is raised from 200 to 400 vehicles. However, DCFROI is much more sensitive and increases by 88% when the production quantity is raised from 200 to 400 vehicles.

#### Effect of Range on DOC and ROI

While the nominal vehicle was designed for a range of 4000 n. mi., the performance of the ATSCV was investigated at other ranges with fuel off loaded. Figure 10 shows how utilization (hours/year) varies with range. This assumes a turn-around time of 45 minutes and a ground

maneuver time of 30 minutes. When the range is decreased from 4000 to 2000 n. mi., the utilization decreases approximately 10%. The utilization is calculated as a function of block time using an empirical relationship which has been developed as a function of block time. Further analysis of the utilization and range relationships would require a route analysis for an ATSCV being used in the commercial airline structure. Figures discussed below will illustrate an important point--the penalty for short ranges is greater than the benefits for long ranges--which should be considered when planning a route structure for the ATSCV.

Figure 11 illustrates the change in DOC as a function of trip length. When the range is decreased from 4000 to 2000 n. mi. the DOC increases almost 50%. Even though the utilization may not have shown a striking sensitivity to range, it has such a strong effect on DOC that a minor change of 10% in utilization results in a 50% change in DOC.

Figure 12 shows the effect of average trip length on DCFROI and CFROI. In order to achieve positive CFROI, the average trip length must be greater than 1400 n. mi.; for DCFROI greater than 10% the average trip length must be above 2800 n. mi. Since a positive DCFROI is essential for any new aircraft, the ATSCV should be flown at trip lengths over 2800 n. mi.

#### Effect of Fuel Cost on DOC and ROI

The cost of fuel has become a major concern when examining the economic feasibility of an aircraft. The nominal fuel price used for this study was \$0.22/gal (ref. 5). The effect of fuel cost changes was investigated to determine the impact over a range of \$0.10/gal to

\$0.60/gal. As was illustrated in figure 2, for the nominal vehicle, fuel accounts for 41.34% of the DOC at the nominal cost (\$0.22/gal). Figure 13 illustrates the effect of fuel cost on DOC. An increase of 50% in fuel cost results in an increase of 21% in DOC.

Figure 14 is a plot of CFROI and DCFROI against fuel cost. At a fuel cost greater than 40¢/gal, the economic feasibility of the ATSCV becomes questionable unless the fare or average load factor is increased.

#### Effect of Load Factor on ROI

Currently, aircraft load factors are averaging around 55% to 60%. Figure 15 shows the strong sensitivity of CFROI and DCFROI to load factor and suggests that load factors less than 40% would be very unattractive. The economic feasibility of the nominal ATSCV requires a relatively high average load factor in order to furnish attractive ROI's.

#### Effect of Fare Level on ROI

In the case of load factor under 40%, one alternative for increasing the ROI would be to charge a premium fare for ATSCV travel. The nominal fare used in this study was \$12.00 per boarding plus \$0.0658 per n. mi. Figure 16 shows the effect on ROI of varying the basic fare from its nominal value at load factors of 30%, 40%, and 55%. While a 30% load factor is never really competitive even at higher fares, a 40% load factor could have an ROI as attractive as the nominal case if a 30% fare surcharge is applied.



## CONCLUDING REMARKS

Using the values assumed for the nominal vehicle (table 1), the ATSCV evolved from the LTV study is an economically productive aircraft with an idealized DCFROI of 50%. However, the economic attractiveness of the vehicle (based on its ability to return a DCFROI greater than the 20% that is considered a typical profitability objective for an average risk venture) is dependent on several factors. With all the other variables held fixed at their nominal values, maintaining a 20% DCFROI requires an aircraft unit cost less than \$90 million or a production run of at least 200 vehicles, an average trip length of 3000 miles or greater, a fuel cost of less than 38¢/gallon, an average load factor greater than 47%, or a fare surcharge if any of these factors cannot be met.

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TABLE 1 - NOMINAL STUDY VALUES

GROSS TAKEOFF WEIGHT	762,000 lb
DESIGN RANGE	4,000 n.mi.
DESIGN CRUISE SPEED	MACH 2.7
NUMBER OF ENGINES	4
THRUST/ENGINE	77,610 lb
PASSENGERS	292 (ALL COACH)
LOAD FACTOR	55 %
TOTAL PRODUCTION QUANTITY	400
FUEL COST	\$ .0335/lb (21.8¢/gal)
INSURANCE RATE	2 %
YEAR DOLLARS	1974
INTEREST RATE	10 %
DEPRECIATION PERIOD	15 YEARS
RESIDUAL VALUE	15 %
UTILIZATION	3647 hrs/yr
CREW	3.0

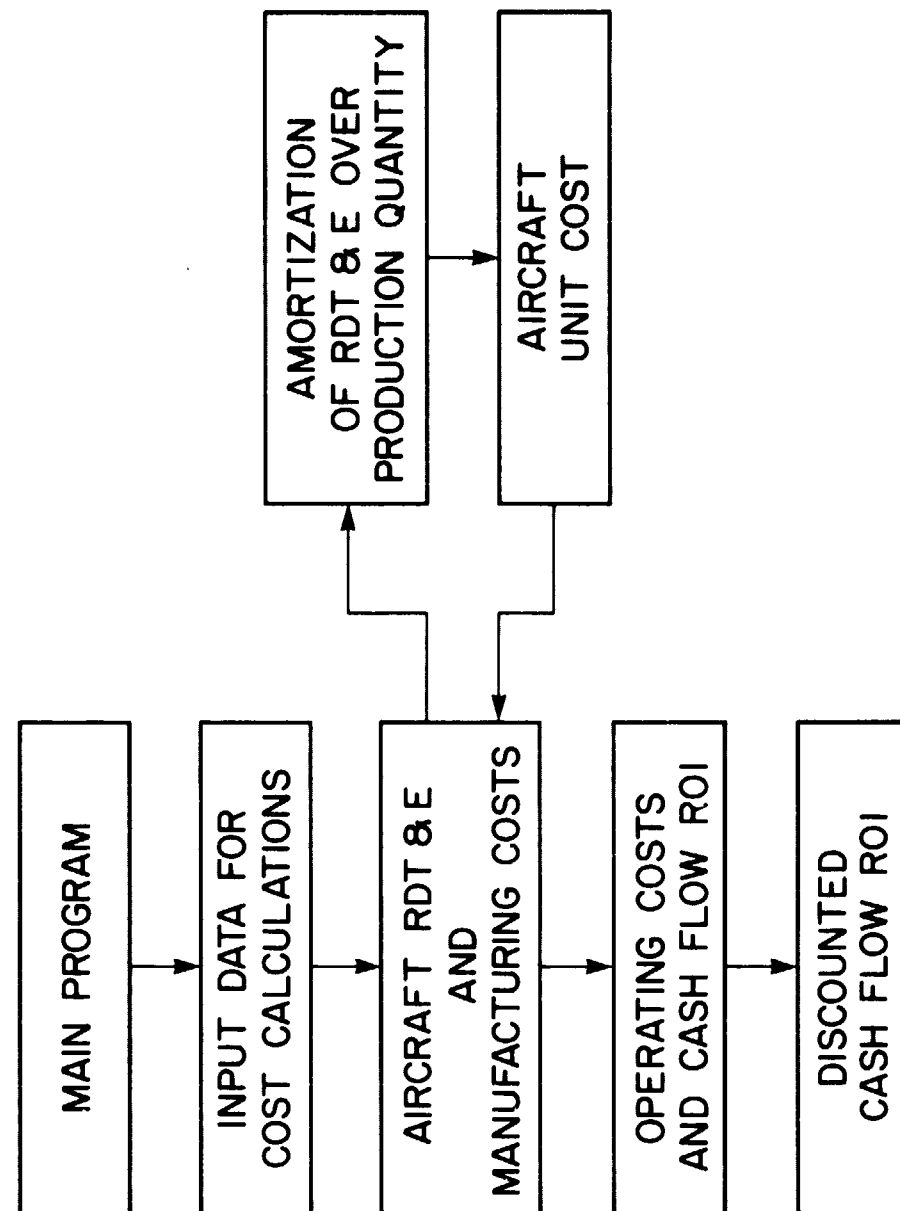


FIGURE 1 - ACCOST (AIRCRAFT COSTING) PROGRAM FLOW.

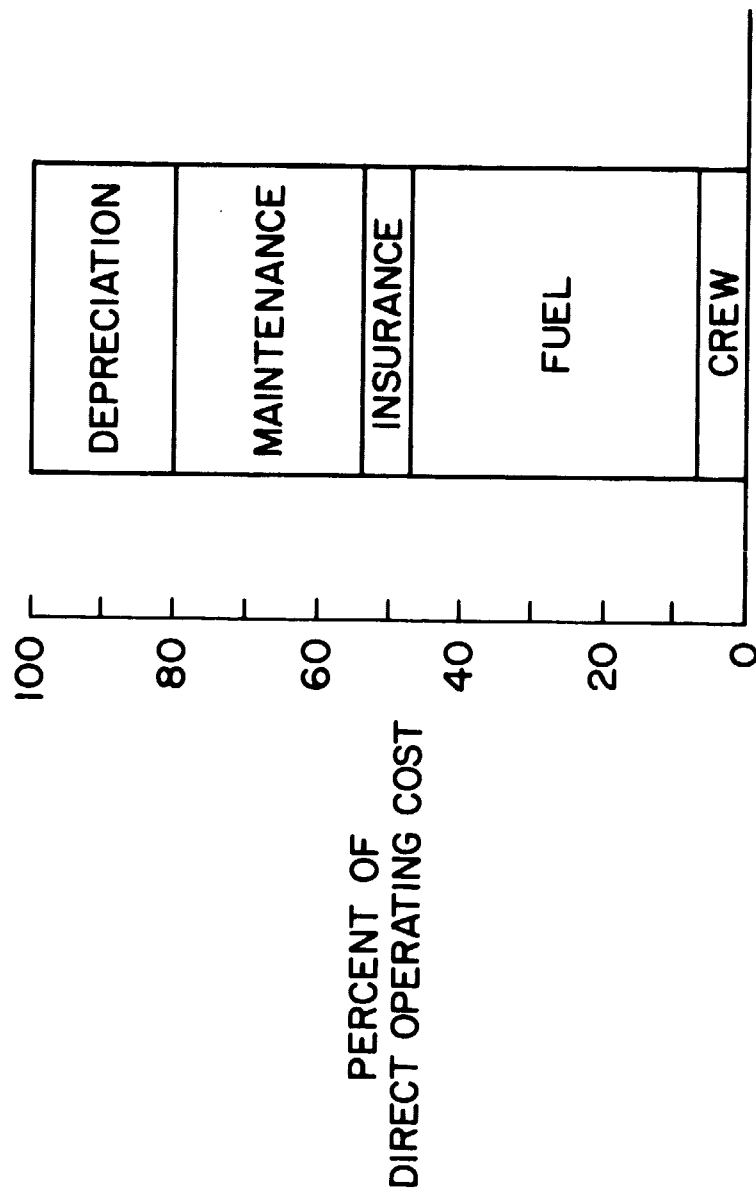


FIGURE 2 - DIRECT OPERATING COST COMPONENTS.

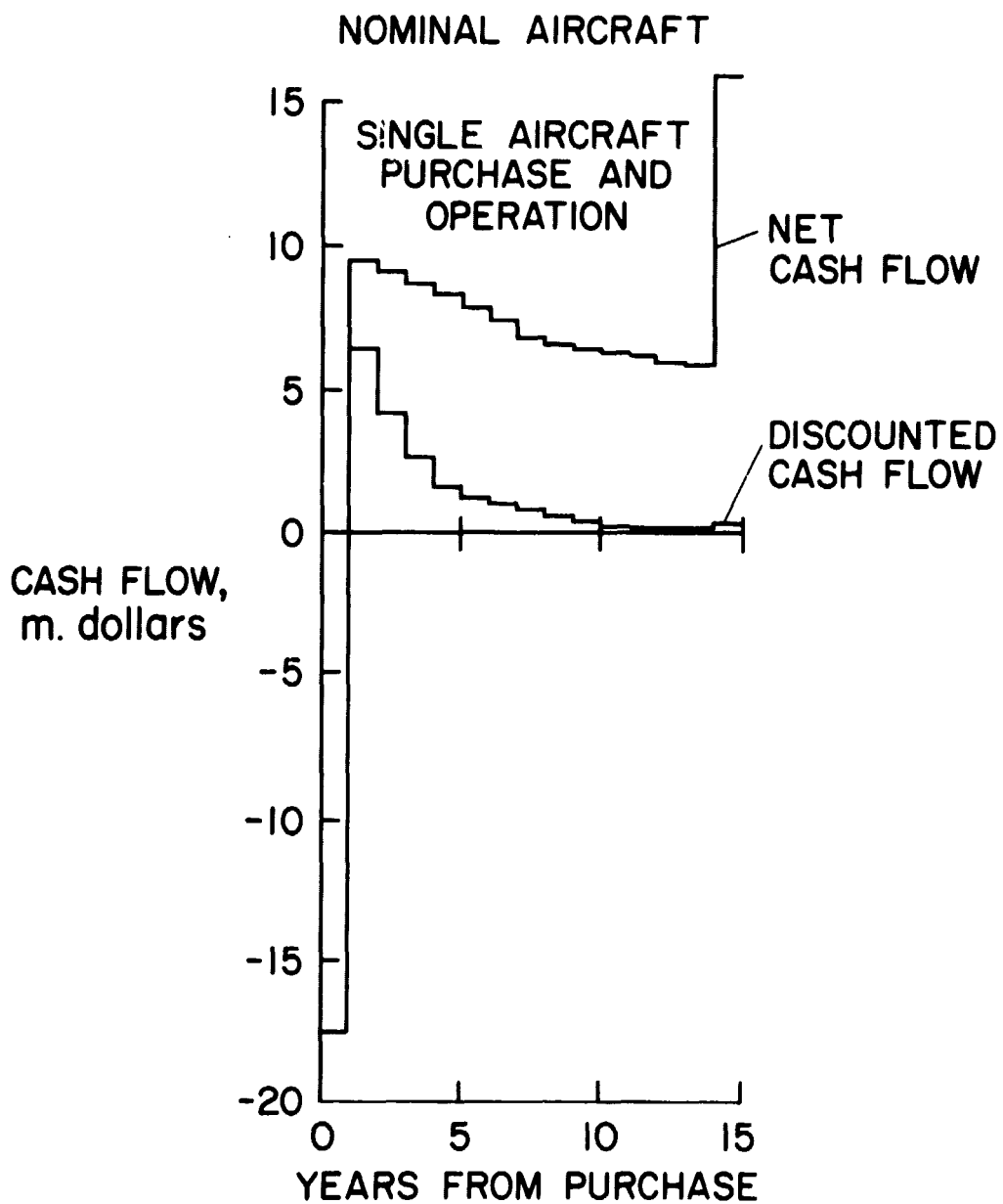


FIGURE 3 - CASH FLOW HISTORY.

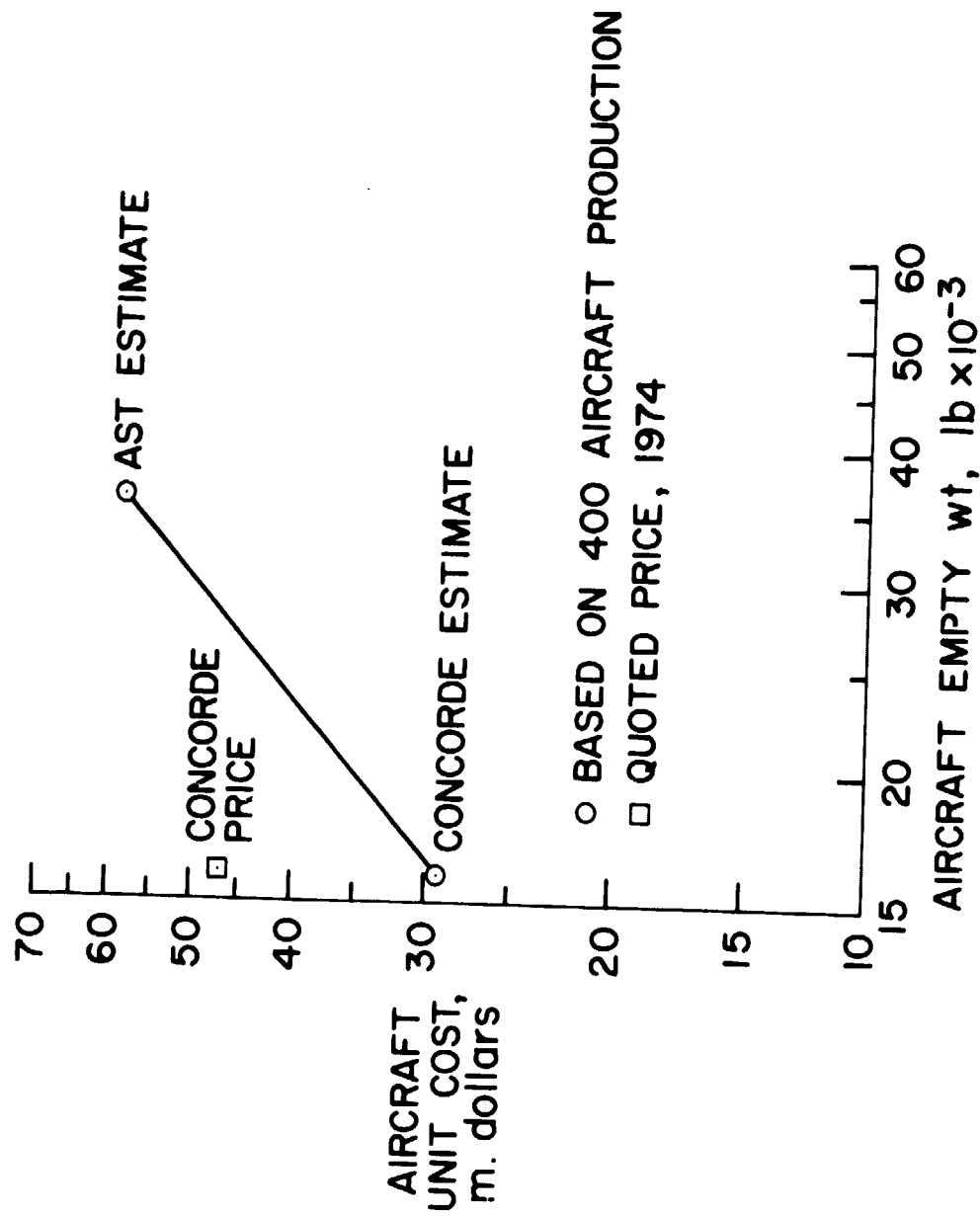


FIGURE 4 - EFFECT OF AIRCRAFT EMPTY WEIGHT ON AIRCRAFT UNIT COST.

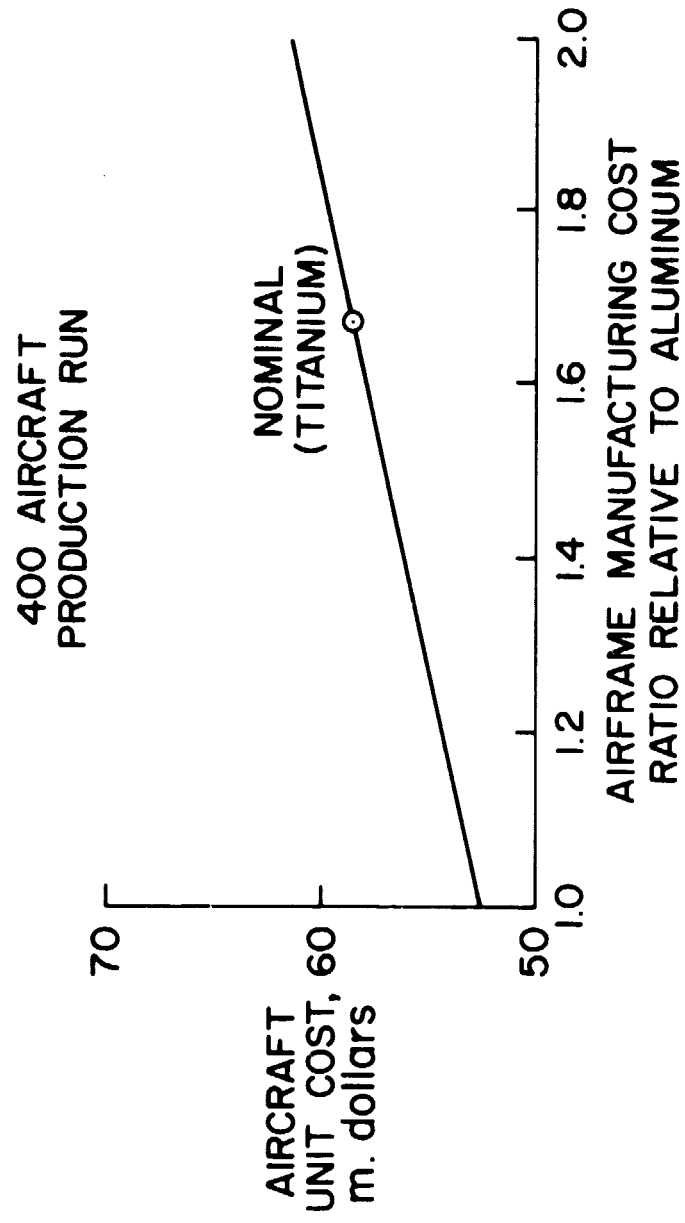


FIGURE 5 - EFFECT OF MANUFACTURING COST ON  
AIRCRAFT UNIT COST.



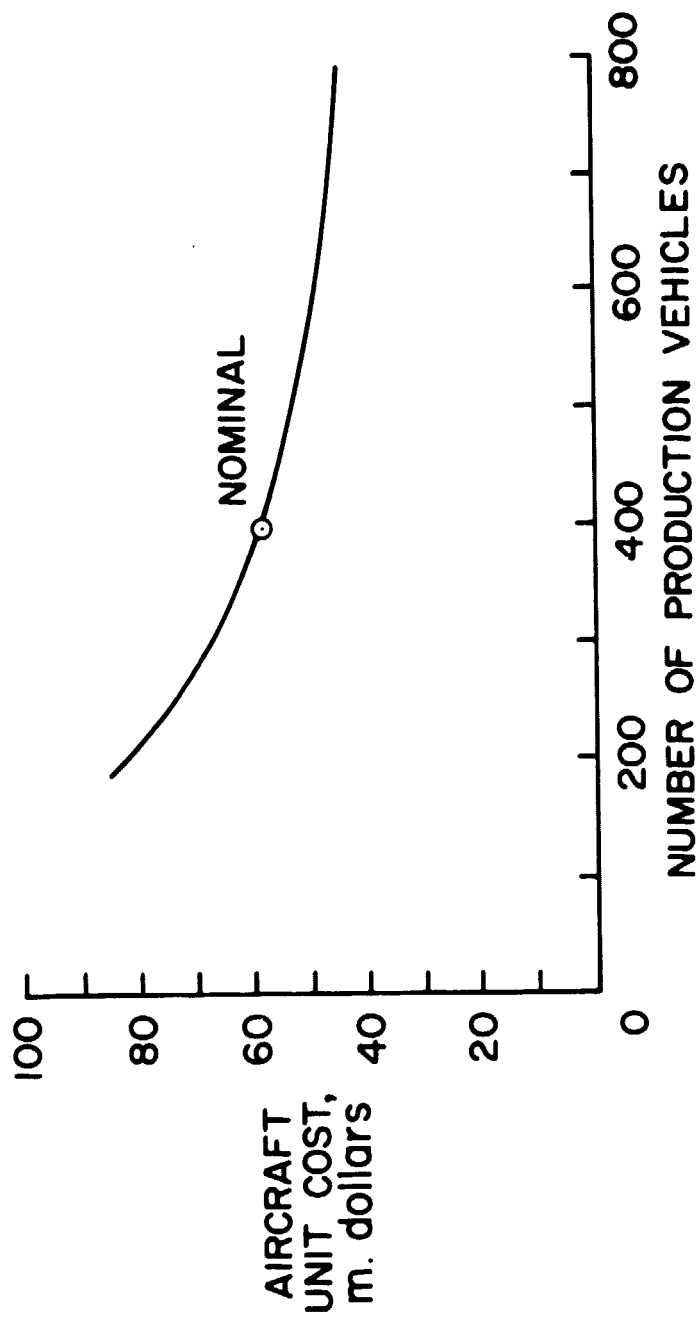


FIGURE 6 - EFFECT OF PRODUCTION QUANTITY ON  
AIRCRAFT UNIT COST.

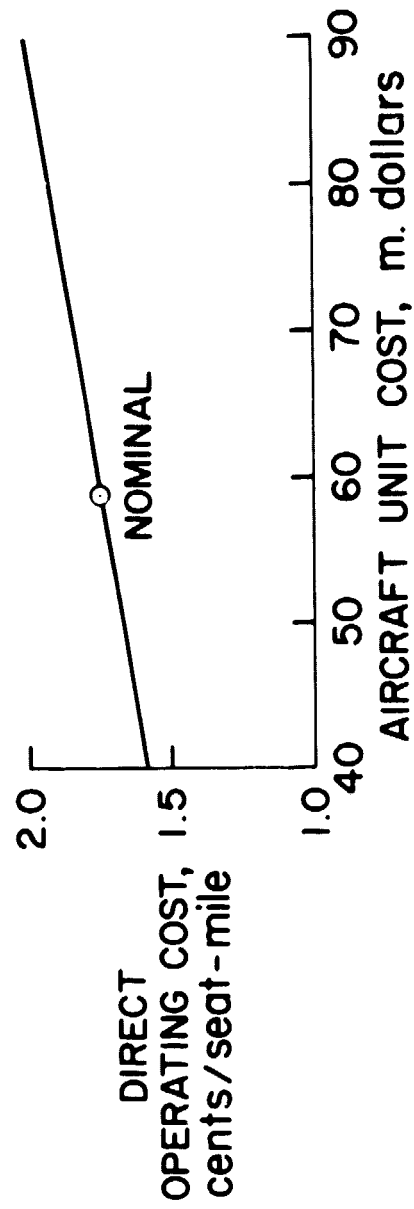


FIGURE 7 - EFFECT OF AIRCRAFT UNIT COST ON  
DIRECT OPERATING COST.

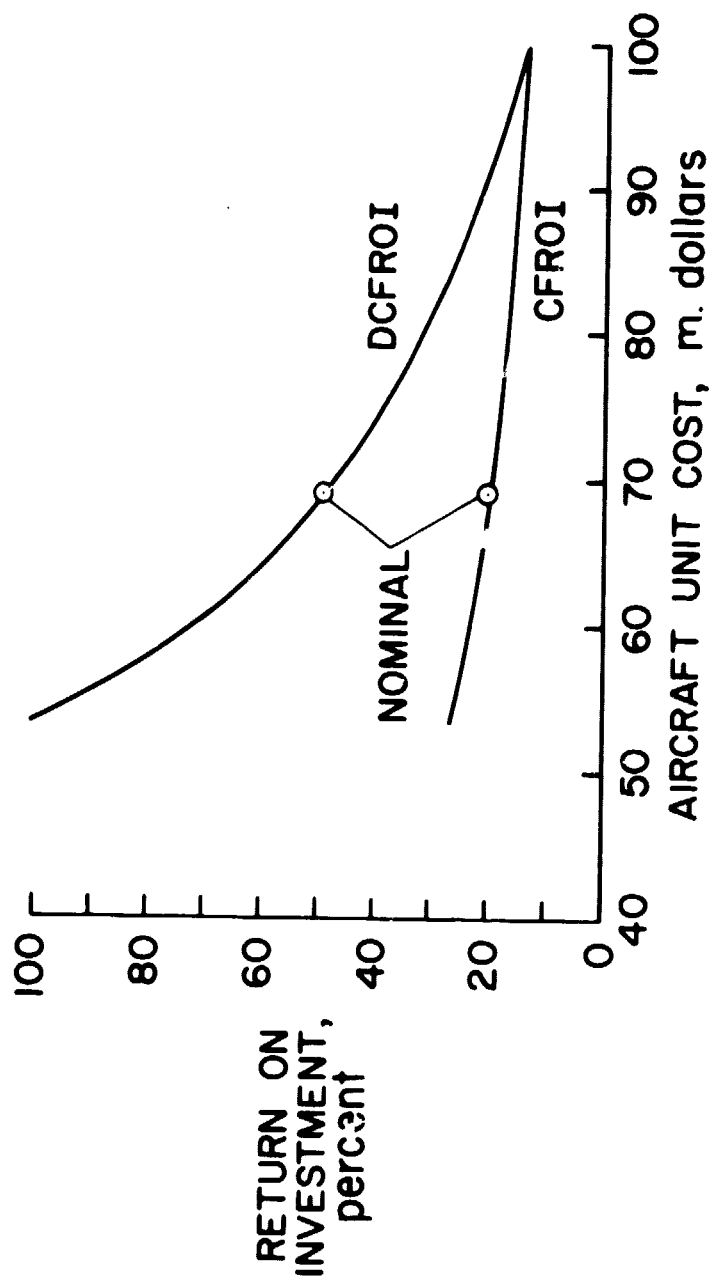


FIGURE 8 - EFFECT OF AIRCRAFT UNIT COST ON  
RETURN ON INVESTMENT.

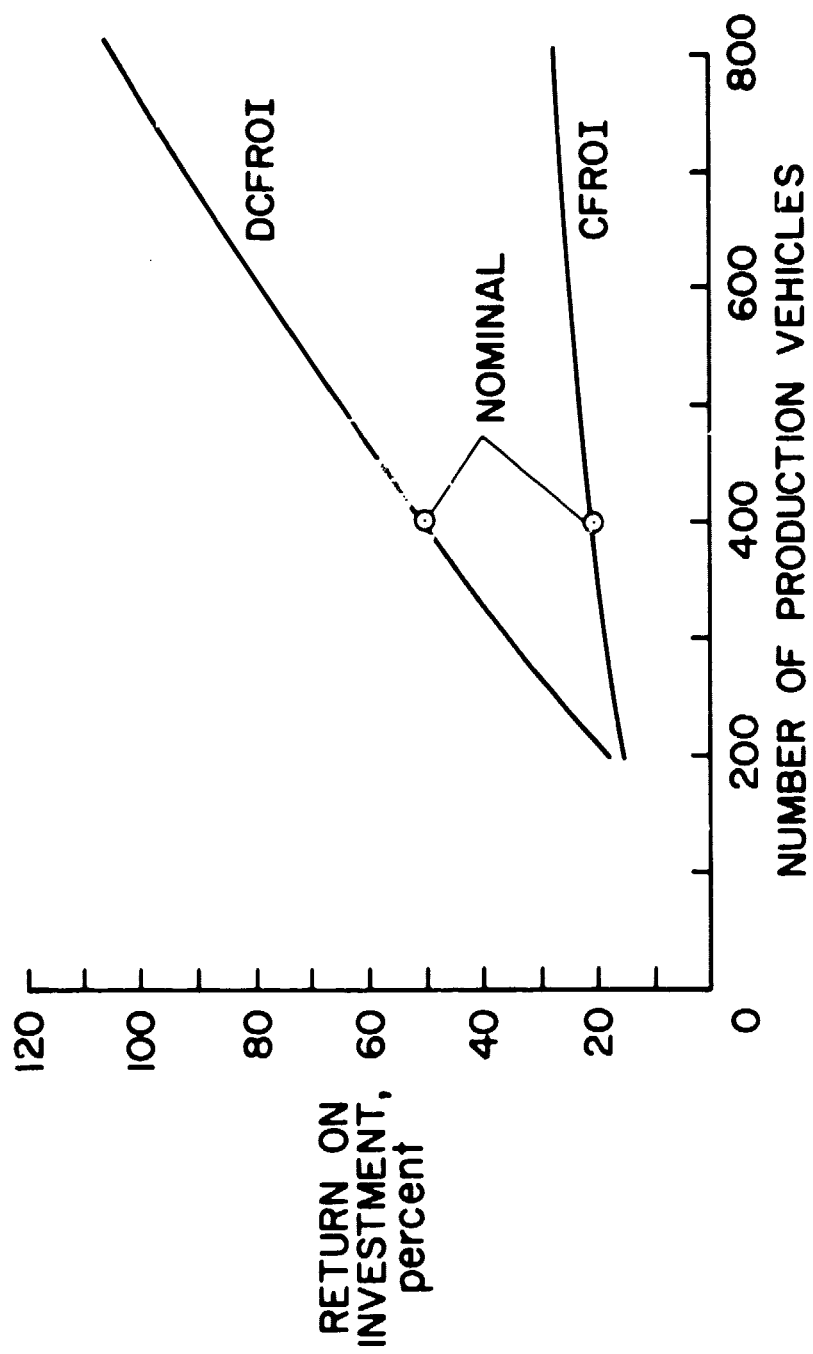


FIGURE 9 - EFFECT OF PRODUCTION QUANTITY ON  
RETURN ON INVESTMENT.

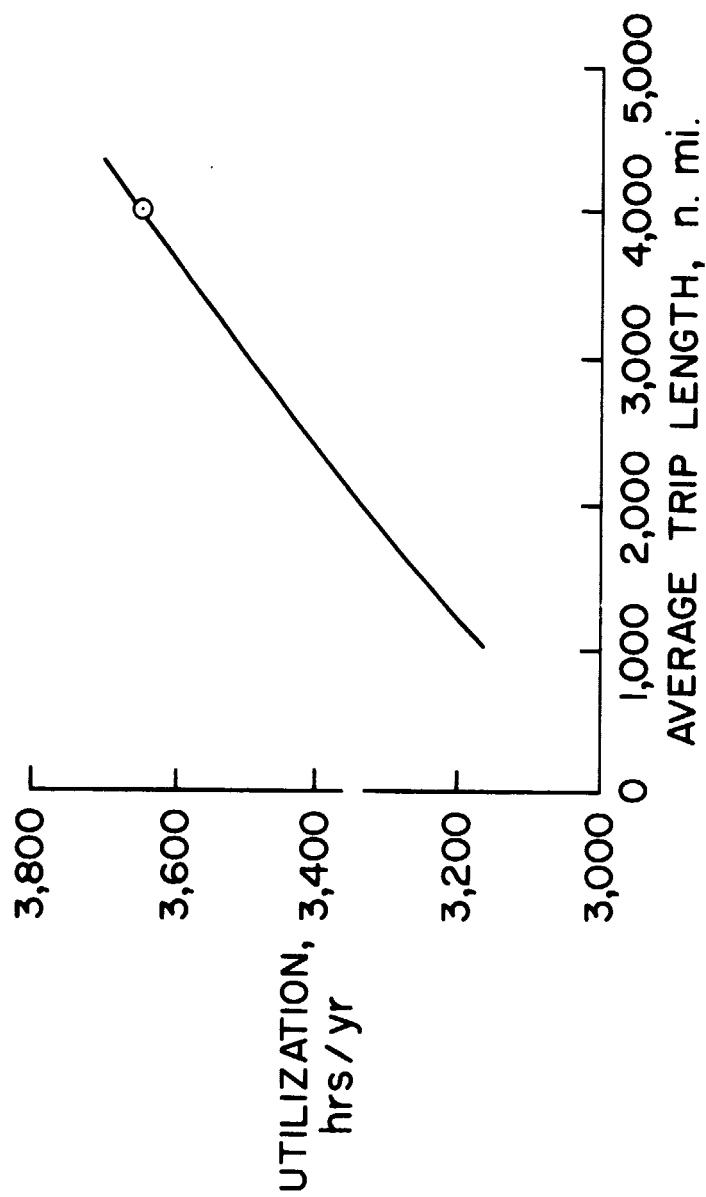


FIGURE 10 - EFFECT OF AVERAGE TRIP LENGTH  
ON ANNUAL UTILIZATION.

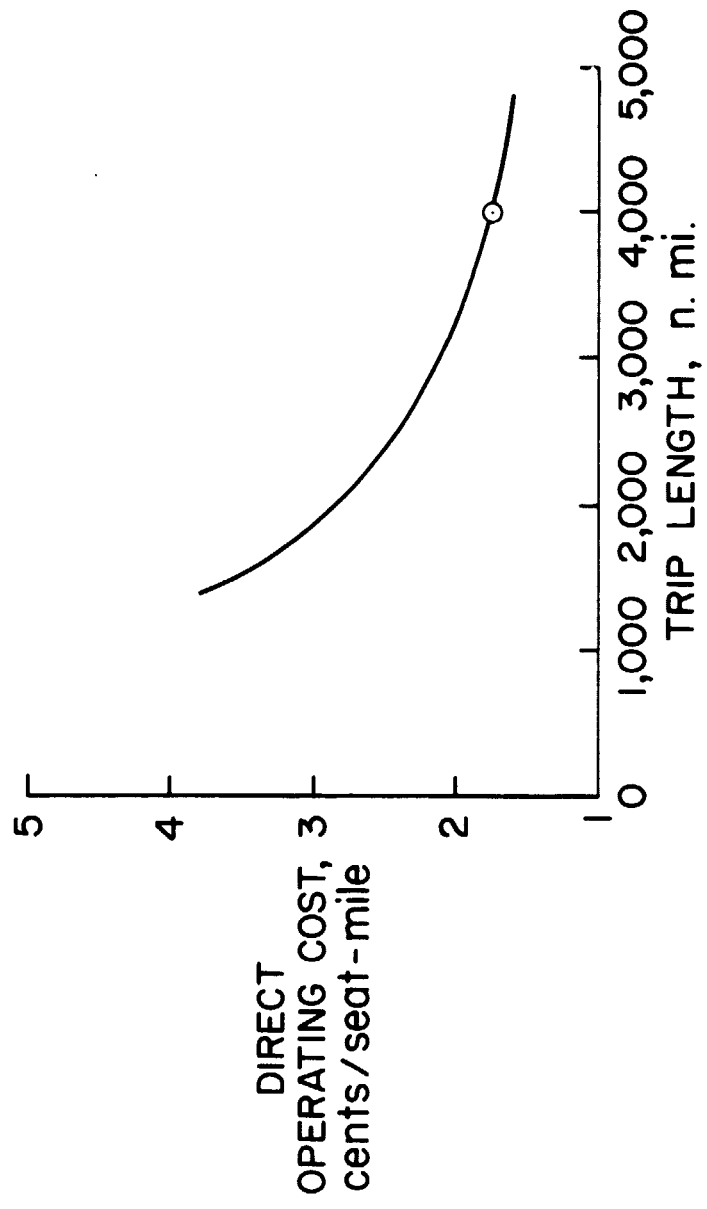


FIGURE 11 - EFFECT OF TRIP LENGTH ON  
DIRECT OPERATING COST.

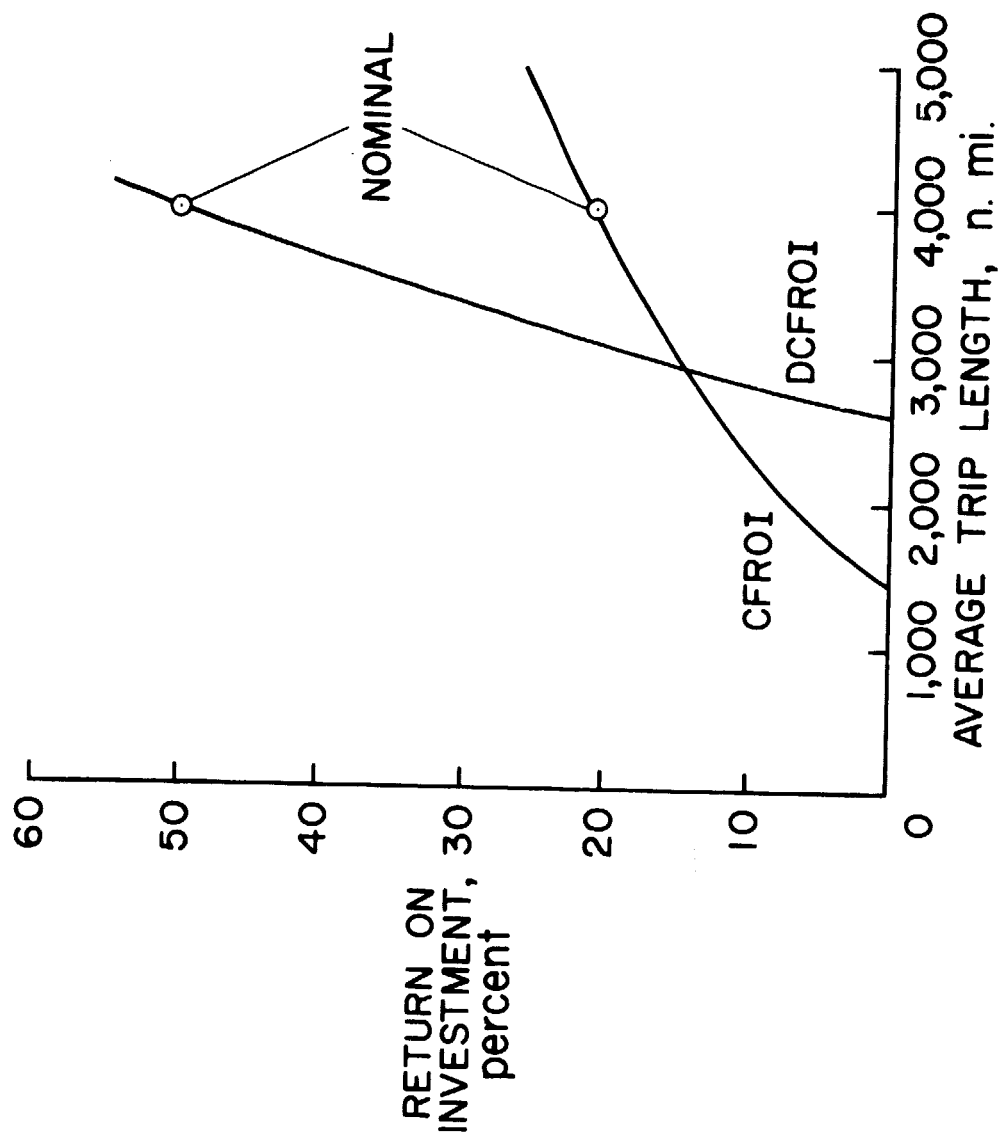


FIGURE 12 - EFFECT OF AVERAGE TRIP LENGTH ON  
RETURN ON INVESTMENT.

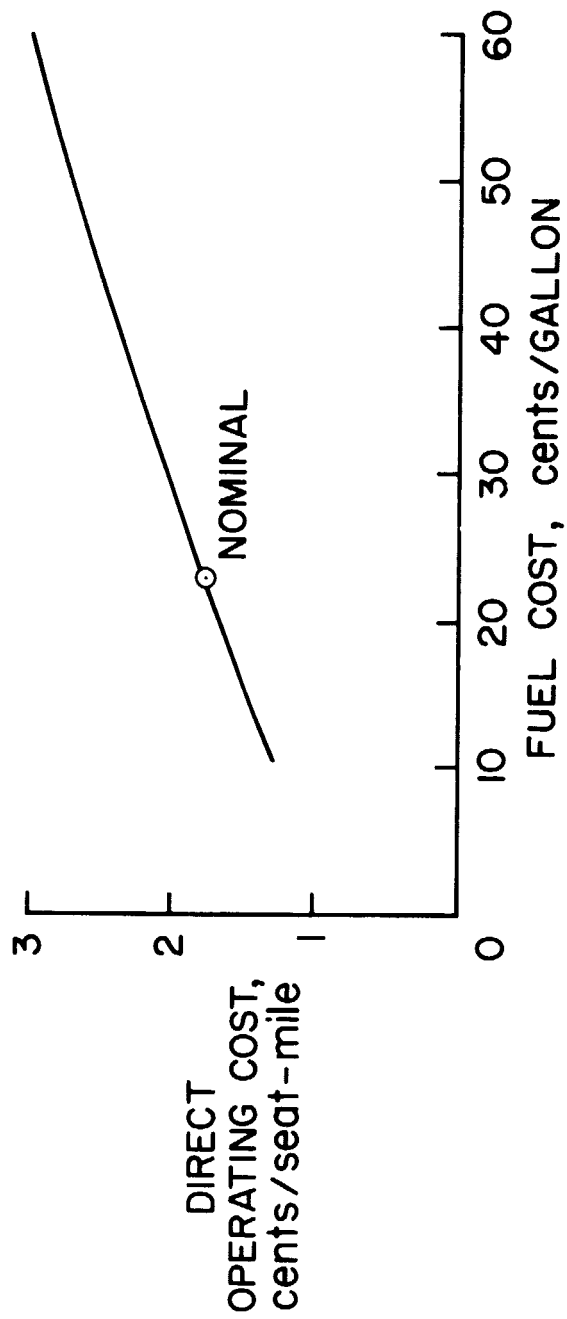


FIGURE 13- EFFECT OF FUEL COST ON  
DIRECT OPERATING COST.



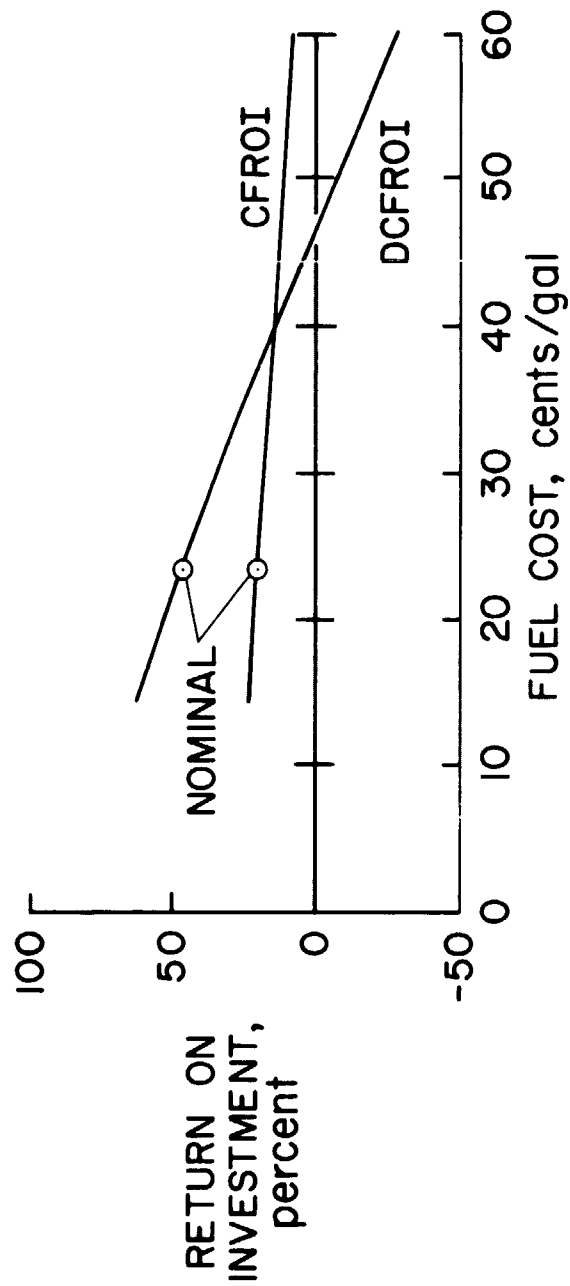


FIGURE 14 - EFFECT OF FUEL COST ON  
RETURN ON INVESTMENT.

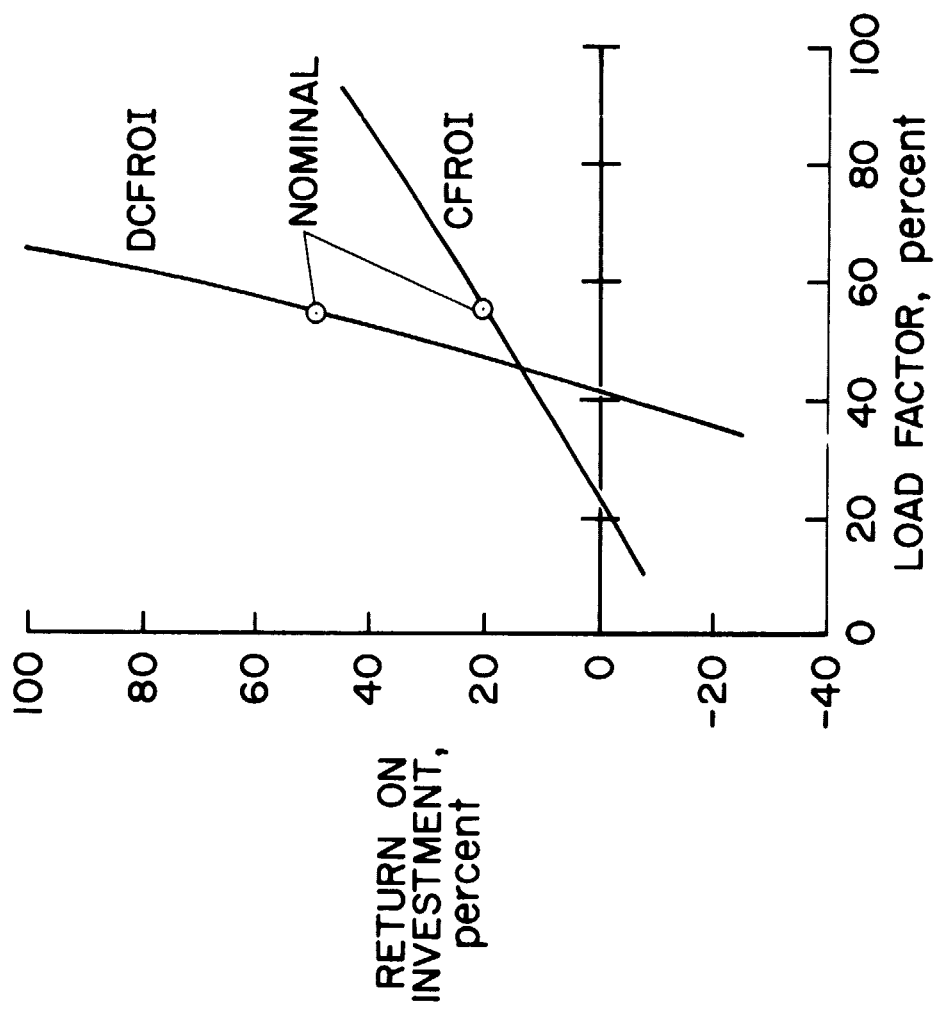


FIGURE 15- EFFECT OF LOAD FACTOR ON  
RETURN ON INVESTMENT.

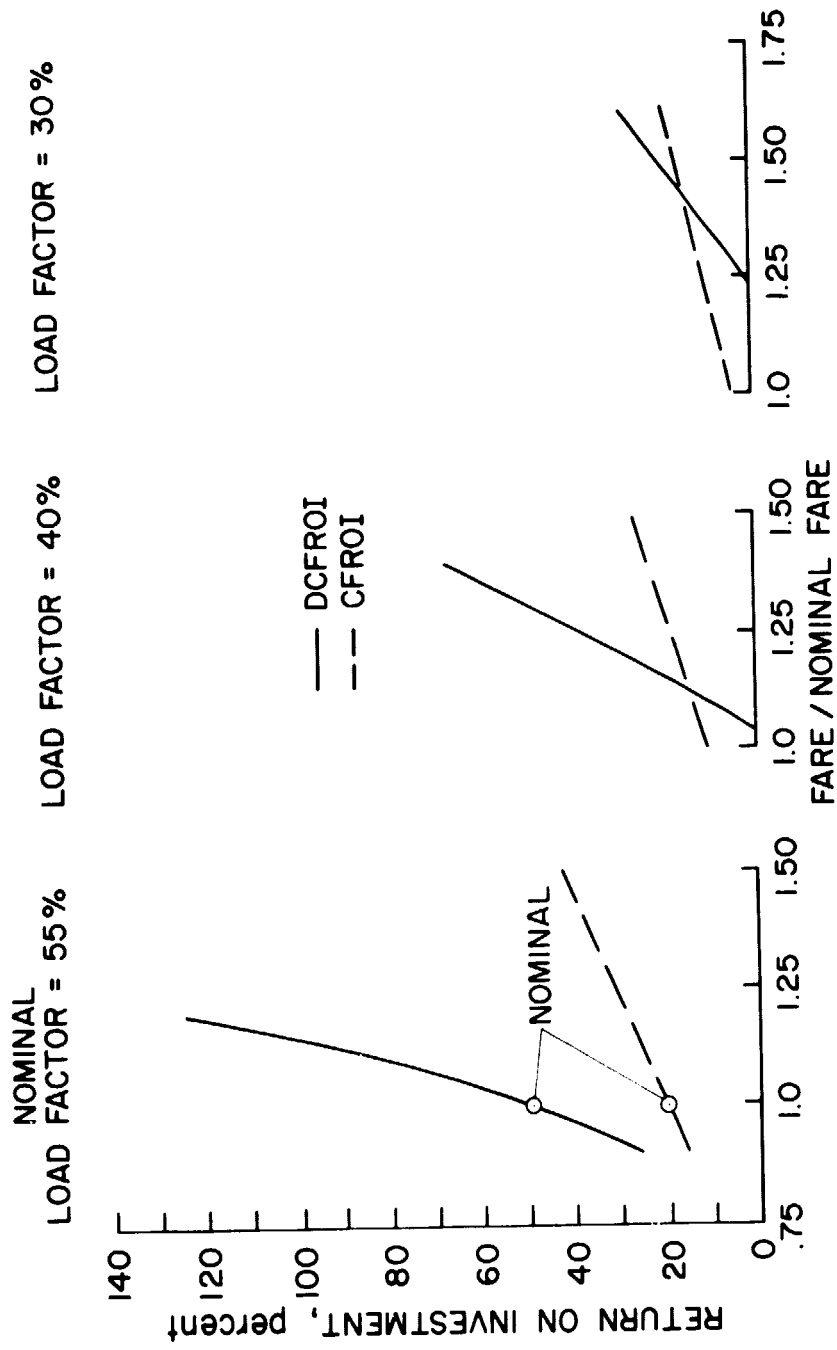


FIGURE 16 - EFFECT OF FARE LEVEL AND LOAD FACTOR  
ON RETURN ON INVESTMENT.